UCRL-ID-125381

Methodology for the Relative Risk Assessment in the NIF Preliminary Safety Analyis Report

S J. Brereton

August 30, 1996

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.
Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

This report has been reproduced
directly from the best available copy.

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401

Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.,
Springfield, VA 22161

Methodology for the Relative Risk Assessment in the NIF Preliminary Safety Analysis Report

1.0 Summary

This document provides the methodology used for the relative risk assessment performed in the NIF Preliminary Safety Analysis Report. The safety analysis for a facility of the hazard level of NIF (low hazard, radiological) should be mostly qualitative. This was the approach taken for the NIF risk assessment, where qualitative descriptors were assigned to event consequences and frequencies. The event consequences and frequencies were then combined using a risk matrix to obtain an assessment of the relative risk presented by each event to NIF workers and to the public. The development of the risk matrices is the main subject of this report. The matrices have been applied in the NIF PSAR (LLNL, 1996).

2.0 Overview of Methodology For Risk Matrix Development

Four risk matrices are developed here: a radiological risk matrix for workers, a radiological risk matrix for the public, a chemical risk matrix for workers, and a chemical risk matrix for the public. Four matrices are needed because the consequence criteria used in establishing the matrices are different for workers and the public, and for radiological and chemical effects. Each is a 4 x 4 matrix, with consequences on the vertical axis and frequency on the horizontal axis.

In order to determine the relative risk presented by each of the 16 blocks of any of the risk matrices, numerical values must be assigned. This is accomplished by providing numerical values to the frequency and consequence axes. The product of the numerical values of frequency and consequence gives a range of numerical values defining the risk for each block. The numerical values for risk are compared and binned into risk ranges, allowing the relative risk of each of the 16 blocks of the matrix to be known. For simplicity and conservatism, the binning is based on the highest numerical value associated with a risk block (as opposed to using the range of values).

The basis for the numerical values for frequencies and consequences is given below. This is followed by the approach used for binning into risk ranges. The risk matrices are provided at the end of the document.

2.1 Frequency Levels

All of the matrices have the same four frequency categories: Frequency Category 1, Frequency Category 2, Frequency Category 3, and Frequency Category 4. Numerical ranges are assigned to each category as given below. These ranges are commonly used for frequency binning, although the name given to a particular category may vary (DOE, 1994; DOE 1989a).

Frequency Category 1:
Condition exists or is expected at the facility ($f > 10^{-1}$ yr^{-1}).

Frequency Category 2:
Incidents that may occur several times during the lifetime of the facility (10^{-1} $yr^{-1} > f > 10^{-2}$ yr^{-1}).

Frequency Category 3:
Accidents that are not anticipated to occur during the lifetime of the facility (10^{-2} $yr^{-1} > f > 10^{-4}$ yr^{-1}).

Frequency Category 4:
Accidents that will probably not occur during the life cycle of the facility (10^{-4} $yr^{-1} > f > 10^{-6}$ yr^{-1}).

Beyond Frequency Category 4:
All other accidents (facility ($f < 10^{-6}$ yr^{-1}).
The probability of occurrence is so small that a reasonable scenario is not conceivable. These events are not considered in the facility design.

2.2 Consequence Levels

The consequence categories are provided below. They were selected to cover the range of potential impacts to workers or the public. Some of the radiological consequences (especially those for the public) are tied to regulations, which are more related to long term exposures and chronic health effects such as cancer. They are also somewhat related to public perception, and thus, these consequences are broader than health effects alone. The chemical consequences were selected on the basis of acute health effects[1].

Consequence Category 1:
There is essentially no noticeable impact.
NIF Workers: radiation dose less than 1 mrem (essentially negligible dose, would not be able to discern from background radiation); exposure to chemical concentration less than TLV-TWA[2]

---

[1] None of the chemicals considered in the NIF analysis are carcinogens. If this methodology were to be applied to another situation, where carcinogens were of interest, the methodology should be reviewed to ensure that these types of effects are appropriately included.

[2] TLV-TWA: Threshold Limit Value, Time Weighted Average, is the maximum concentration level of hazardous material to which a worker can be exposed for 8 hours per day, 40 hours per week.

Public: radiation dose less than 1 mrem; exposure to chemical concentration less than TLV-TWA

Consequence Category 2:
The impact is minor; reporting may be required.
NIF Workers: radiation dose less between 1 and 500 mrem (500 mrem is the adopted NIF worker routine exposure limit); exposure to chemical concentration between TLV-TWA or equivalent and ERPG-2[3] or equivalent; worker injury
Public: radiation dose between 1 and 100 mrem (100 mrem corresponds to the public routine exposure limit (DOE, 1990)); exposure to chemical concentration between TLV-TWA and ERPG-1[4] or equivalent

Consequence Category 3:
The impact is significant.
NIF Workers: radiation dose between 500 mrem and 25 rem (There is no "allowable" worker dose from an accident. However, CFRa allows a dose of 25 rem or more to volunteers involved in emergency actions under accident conditions directed at saving life or protection of large populations); exposure to chemical concentration between ERPG-2 or equivalent and ERPG-3[5] or equivalent; lost-time injury, chemical exposure causing significant discomfort or which is somewhat disabling
Public: radiation dose between 100 mrem and 1 rem (1 rem is the threshold for offsite emergency planning (EPA, 1991)); exposure to chemical concentration between ERPG-1 or equivalent and ERPG-2 or equivalent, i.e. measurable chemical exposure

Consequence Category 4:
The impact is severe.
NIF Workers: radiation dose above 25 rem (acute health effects (e.g. changes in the blood) may be observed above this exposure (Dalrymple, 1973)); exposure to chemical concentration above ERPG-3 or equivalent i.e. death, disability, potential severe short-term health effects.
Public: radiation dose above 1-5 rem (emergency action, such as evacuation required (EPA, 1990)) with an upper bound of 25 rem (siting requirement (CFRa, DOE, 1989c); exposure to chemical concentration between ERPG-2 or equivalent and ERPG-3 or equivalent.

---

[3]ERPG-2: Emergency Response Planning Guide, Level 2, as defined by the American Industrial Hygiene Association, is the maximum airborne concentration level of hazardous material below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their ability to take protective action.

[4] ERPG-1: Emergency Response Planning Guide, Level 1, as defined by the American Industrial Hygiene Association, is the maximum airborne concentration level of hazardous material below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

[5]ERPG-3: Emergency Response Planning Guide, Level 3, as defined by the American Industrial Hygiene Association, is the maximum airborne concentration level of hazardous material below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening effects.

The chemical consequence criteria require further development, as the determination of relative risk within the matrices requires numerical values. Determining relative risk levels for chemicals is somewhat more complicated than for radiological events. It is not straightforward to make generalizations for chemical consequences because each chemical has a unique set of numerical evaluation criteria (i.e. TLVs, ERPGs, etc. are different for each chemical), and different physiological effects. However, it is possible to make some general statements regarding the relative values of the criteria selected here for the consequence categories. It is possible to express the chemical consequences in terms of a common unit. Craig et al. (1993) have provided guidance on selection criteria for ERPG-equivalent values, when actual ERPG values are not available. They indicate that one can use 3 x TLV-TWA as a representative value for ERPG-1, and 5 x TLV-TWA as a representative value for ERPG-2. Craig et al. (1993) do not provide a representative value for ERPG-3 in terms of TLV-TWA, but one can be derived. In comparing actual ERPG values, it was observed that the ERPG-3 value is often a factor of 5 or so greater than the ERPG-2 value. Thus, 5 x ERPG-2 = 5 x (5 x TLV-TWA) = 25 x TLV-TWA could be used as a representative value for ERPG-3 for the purpose of assigning relative consequences. Using the TLV-TWA as the basis (i.e. consequence value of 1), relative numerical values can be assigned to each of the chemical consequence categories, as shown below.

<u>Chemical Consequence Category 1</u>:

NIF Workers: exposure to chemical concentration less than TLV-TWA; in relative terms, less than 1

Public: exposure to chemical concentration less than TLV-TWA; in relative terms, less than 1

<u>Chemical Consequence Category 2</u>:

NIF Workers: exposure to chemical concentration between TLV-TWA and ERPG-2 or equivalent; in relative terms, between 1 and 5

Public: exposure to chemical concentration between TLV-TWA and ERPG-1 or equivalent; in relative terms, between 1 and 3

<u>Chemical Consequence Category 3</u>:

NIF Workers: exposure to chemical concentration between ERPG-2 or equivalent and ERPG-3 or equivalent; in relative terms, between 5 and 25

Public: exposure to chemical concentration between ERPG-1 or equivalent and ERPG-2 or equivalent; in relative terms, between 3 and 5

<u>Chemical Consequence Category 4</u>:

NIF Workers: exposure to chemical concentration above ERPG-3 or equivalent; in relative terms, above 25, up to and including death

Public: exposure to chemical concentration between ERPG-2 or equivalent and ERPG-3 or equivalent; in relative terms, between 5 and 25.

Radiological consequences are expressed in mrem, with a 1 mrem value being associated with Consequence Category 1. On the chemical side, a chemical concentration equivalent to TLV-TWA is assigned a relative consequence value of 1. This does not mean that a dose of 1 mrem is equivalent to being exposed to a chemical concentration at the TLV-TWA level. No equivalence between these consequences is implied. This is the case for all consequence categories, with the exception of the upper bound for worker consequences, which is death.

In order to complete the assignment of numerical consequences, a numerical value is needed for death. From a radiological standpoint, death from an acute exposure may be observed at a dose as low as about 200 rad (without medical intervention, probability of death is about 5% (Dalrymple, 1973)). The probability of death increases as dose increases. The LD50/30 (lethal dose to half the population within 30 days of exposure, without medical intervention) is about 400 rad. There is a very high probability of death for doses in excess of 600 rad (Dalrymple, 1973). The sources of radiation at NIF for potentially high exposure events are neutrons and gammas (prompt and decay radiation). The Quality Factor for high energy neutrons is 2.5 - 3; the Quality Factor for gammas is 1. Considering this, the lethal exposure of 600 rad can be expressed in terms of biological effect as doses ranging from 600 rem (gamma) to 1800 rem (neutrons). Since the actual value selected here is not critical, an intermediate value of 1000 rem was selected for use in the risk matrix. This dose has a high probability of a maximum consequence of death associated with it, and should reasonably bound all radiological consequences.

From a chemical standpoint, it is expected that there would be a wide variability in the relative values of the ERPG-3 concentration and a life threatening concentration. There is not always human data available to determine the relative values quantitatively. For example, none was found for methanol, a chemical of interest for NIF. However, animal data were found, and they indicate that death occurs at a concentration of approximately 5-20 times the ERPG-3-equivalent concentration. Comparable data on mercury, another chemical of interest for NIF, were not found. Animal data is not always directly translatable to humans, but it provides at least a starting point. For other chemicals, such as chlorine, the lowest lethal concentration for humans is given as about 20 times the ERPG-3 concentration. Although chlorine is not directly of interest here (there is an external event impacting NIF, which involves chlorine), this data provides another benchmark. Given this information, a representative value of 20 x ERPG-3(-equivalent) or 20 x 5 x 5 x TLV-TWA = 500 x TLV-TWA was chosen here as a reasonable upper bound concentration, and should encompass lethal concentrations for many chemicals. If this methodology is used in other applications, selection of this factor of 20 should be reviewed for the specific chemicals of interest to verify its reasonableness. The exact value selected here is not critical, as chemical consequences of this magnitude are not expected at NIF.

3.0 Assignment of Risk Ranges

Risk is the product of frequency and consequence. For each block in the 4 risk matrices the corresponding numerical values for frequencies and consequences were multiplied, providing a numerical value for the risk. Since the frequencies and consequences span a range of values, the risk will also span a range of values. To simplify the process, and to be conservative, the highest values of frequency and consequence corresponding to a given block were used to determine a value for risk. These values are indicated on Figures 1 through 4.

As an example, for worker radiological events (Figure 1), Consequence Category 2 ranges from 1 to 500 mrem, and Frequency Category 2 ranges from 10^{-2} to 10^{-1} /yr. The numerical values for risk for the block on Figure 1 corresponding to Consequence Category 2 and Frequency Category 2 would range from 10^{-2} to 50.

For simplicity and conservatism, the highest value, 50, is used in the risk binning, and this value is shown on the figure. This process was similarly applied to give the numerical values on all of the blocks in Figures 1 through 4.

The next step was to identify blocks of the matrices, which represent similar risk. This was done by establishing four risk bins, representing four risk levels. Four risk levels were thought to be adequate to allow for enough distinction between events on a 4x4 matrix. These were identified as Risk Levels 1 through 4, with Risk Level 1 representing the lowest risk, and Risk Level 4 representing the highest risk. Since radiological and chemical consequences are not directly comparable (i.e., the health effects associated with a consequence category are not necessarily comparable, except at the upper bound for workers), the risks are also not directly comparable. The radiological risks span Radiological Risk Level 1 through Radiological Risk Level 4; the chemical risks span Chemical Risk Level 1 through Chemical Risk Level 4.

Two premises were identified on which the binning and Risk Level selection were based:

(1) The risk associated with an event in Frequency Category 1 and resulting in the upper bound Category 1 consequence to the public would be the upper bound for risk in Level 1.

(2) The risk associated with an event in Frequency Category 2 (event occurring sometime during the life of the facility) resulting in the death of a worker (i.e. upper bound for Category 4 consequence for workers) would be the lower bound for risk in Level 4.

The other risk levels were selected to fit between these bounds.

Because the radiological and chemical risk matrices span different numerical ranges of risk, the actual values used for binning are different. Each of these is discussed below.

3.1 Radiological Risk Ranges

Figures 1 and 2 present the risk matrices, and numerical values associated with each risk block for radiological risk to workers and to the public.

An upper bound for Risk Level 1 can be obtained from premise 1 noted above. This would correspond to the highest numerical value of risk associated with a Category 1 consequence to the public from a Frequency Category 1 occurrence. The highest numerical value associated with a Category 1 consequence to the public is 1 (mrem). The highest frequency associated with a Frequency Category 1 event is 1 (yr^{-1}). Thus, the numerical value for the risk would be 1, and Radiological Risk Level 1 would include all blocks on Figures 1 and 2 with numerical values of risk less than or equal to 1.

A lower bound for Radiological Risk Level 4 can be obtained from premise 2 noted above. In this case, the value would correspond to the least likely event that could occur during the life of a facility (i.e. in Frequency Category 2) that could result in death to a worker. The low end of the Frequency Category 2 range is 10^{-2} (yr^{-1}).

The numerical value associated with death was selected at 1,000 rem (10^6 mrem). The product of frequency and consequence gives a numerical value of 10^4, which is set as the lower bound for Radiological Risk Level 4. Thus, Radiological Risk Level 4 would include all blocks on Figures 1 and 2 with numerical values of risk greater than 10^4.

The other two risk ranges were assigned to fit between these bounds as noted below:

Radiological Risk Level 1: risk value ≤ 1
Radiological Risk Level 2: $1 <$ risk value $\leq 10^2$
Radiological Risk Level 3: $10^2 <$ risk value $\leq 10^4$
Radiological Risk Level 4: risk value $> 10^4$

Continuing with the previous example, the block containing a worker radiological event with Consequence Category 2 and Frequency Category 2 was found to have a numerical risk value of 50. Comparing to the criteria given above, this block would fall into Radiological Risk Level 2. It is shaded accordingly in Figure 1.

3.2 Chemical Risk Ranges

Figures 3 and 4 present the risk matrices, and numerical values associated with each risk block for chemical risk to workers and to the public.

As with the radiological risk, an upper bound for Chemical Risk Level 1 for chemical risk can be obtained from premise 1 noted above. This would correspond to the highest numerical value of risk associated with a Category 1 consequence to the public from a Frequency Category 1 occurrence. The highest numerical value associated with a Category 1 consequence to the public is 1 (corresponding to a concentration equal to the TLV-TWA). The highest frequency associated with a Frequency Category 1 event is 1 (yr^{-1}). Thus, the numerical value for the risk would be 1, and Chemical Risk Level 1 would include all blocks on Figures 3 and 4 with numerical values of risk less than or equal to 1.

As with the radiological risk, a lower bound for Chemical Risk Level 4 can be obtained from premise 2 noted above. In this case, the value would correspond to the least likely event that could occur during the life of a facility (i.e. Frequency Category 2 event) that could result in death to a worker. The low end of the Frequency Category 2 range is 10^{-2} (yr^{-1}). The numerical value associated with death was selected at 500 (500 x TLV-TWA). The product of frequency and consequence gives a numerical value of 5. Thus, Chemical Risk Level 4 would include all blocks on Figures 3 and 4 with numerical values of risk greater than 5.

The other two risk ranges were assigned to fit between these bounds as noted below:

Chemical Risk Level 1: risk value ≤ 1
Chemical Risk Level 2: $1 <$ risk value ≤ 3
Chemical Risk Level 3: $3 <$ risk value ≤ 5
Chemical Risk Level 4: risk value > 5

4.0 Assignment of Relative Risk

The numerical values on each risk matrix (obtained by multiplying the appropriate consequence value and frequency value) were compared to the risk range values given in the previous section. This allowed each of the risk blocks to be assigned a Risk Level. In each of the four figures, blocks of similar risk level were shaded the same. The shading of each block will allow one to determine if an event in that risk block presents more or less risk than an event in another risk block.

Some observations can be made regarding the risk matrices. In comparing Figures 1 and 2, the radiological risk matrices, it is apparent that the region of low risk (Radiological Risk Level 1) has expanded for the public, while that of Radiological Level 4 risk has become smaller. This is a direct result of the lower consequence values assigned to the public consequence categories. Because the numerical consequence criteria are lower for the public, the risk value for a given block will be lower. Since the risk binning process uses the same numerical values for workers and the public, more blocks from the public risk matrix will fall into the lower risk levels. When placing the blocks of a risk matrix into risk bins, the workers and the public are viewed the same, i.e. the same criteria are used. In effect, this normalizes the risk to both populations.

The figures indicate (by similar shading of the risk blocks that are being compared) that a Frequency Category 3 event resulting in a Category 4 consequence to a worker (including death) presents similar risk to a Frequency Category 2 or 3 event resulting in evacuation of the public (Category 4 consequence). Or, a Frequency Category 4 event resulting in a Category 4 consequence to a worker (including death) presents similar risk to a Frequency Category 1 event occurring with a Category 2 consequence to the public.

Similar statements can be made when comparing Figures 3 and 4 for chemical risk. The region of Chemical Level 1 risk is larger and the region of Chemical Level 4 risk is smaller for the public than for workers for the same reasons as noted above.

Additional observations can be made by comparing the radiological risk matrix and the chemical risk matrix for each of the population groups. For both workers and the public, the region of Level 1 risk in the chemical matrices has expanded, that of Level 2 and 3 risk is reduced, and that of Level 4 risk has remained the same. This is attributable to two features of the consequence scales: (1) the chemical consequences span a much smaller range of consequence space, e.g., relative values from 1 to 500 overall, compared to from 1 to 10^6 for the radiological consequences, and (2) the range of consequences spanned by the individual consequence categories varies (e.g., Category 2 ranges from 1-100 for public radiological consequences, and 1-3 for public chemical consequences), and is the same order only for the Category 4 consequence category. If consequence criteria for chemical and radiological exposures were derived from the same basis (i.e., acute health effects alone), the risk matrices would be expected to be more similar. However, many of the radiological consequence criteria are based on regulatory values, which are more related to long term exposures and chronic health effects such as cancer (and also have wider ramifications than health effects, such as public perception); whereas the chemical consequence criteria are directly associated with some level of acute health effect.

5.0 Application of Risk Matrices

To make use of the risk matrices, it is first necessary to identify events that will or might occur at the facility. This is accomplished through a detailed hazards analysis. Each event should then be assigned frequency and consequence descriptors. For most events, there will be two consequences descriptors: one for the public and one for workers. In some cases, a given event may affect only one population. It is not necessary to quantitatively evaluate a frequency and consequence for each event. These only need to be known well enough to place an event into a category (i.e. known within a range of values). The criteria for the frequency and consequence categories given here are to be used as guidelines. The frequency and consequences associated with an event, can be based on judgment, or estimated from existing documentation on the facility of interest or other similar facilities. For NIF, documents such as the Preliminary Hazards Analysis (Brereton, 1993), the Conceptual Design Report (LLNL, 1994), the Project Specific Analysis for NIF in the Programmatic Environmental Impact Statement for Stockpile Stewardship and Management (DOE, 1996) were used, along with safety documentation for other fusion facilities.

Once frequencies and consequences have been assigned to all events identified for the facility, the relative risk associated with each event can be determined. Each event should be reviewed and placed in the appropriate block of the relevant matrix or matrices (two matrices would be used if an event can affect both workers and the public). The relative risk is determined from the shading of the block where the event is placed.

Once the relative risk of all events identified for a facility is known, those presenting higher risk can be studied in more detail. Events presenting relatively higher risk would be readily identified by this process and might be candidates for risk reduction.

6.0 References

Brereton, S. J. (1993), "Preliminary Hazards Analysis for the National Ignition Facility", UCRL-ID-116983, Lawrence Livermore National Laboratory, October 1993.

CFRa, "Occupational Radiation Protection", Code of Federal Regulations, 10CFR835.

CFRb, "Reactor Site Criteria", Code of Federal Regulations, 10CFR100.

Craig, D.K. et al. (1993), "Toxic Chemical Hazard Classification and Risk Acceptance Guidelines for Use in Nuclear Facilities", Progress Report of the Westinghouse M&O Subcommittee on Non-Radiological Risk Acceptance Criteria Development, SRT-RAM-930001, January 11, 1993.

Dalrymple, G., et al. (1973), Editors, "Medical Radiation Biology", Saunders Co., 1973.

DOE (1996), "Draft Programmatic Environmental Impact Statement for Stockpile Stewardship and Management", Volume III, Appendix I, "Project Specific Analysis for the National Ignition Facility", DOE/EIS-0236, U.S. Department of Energy, July 1996.

DOE (1994), "Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports, DOE Standard, DOE-STD-3009-94, U.S. Department of Energy, July 1994.

DOE (1989a), "Safety Analysis and Review System", San Francisco Operations Office Management Directive, SAN MD 5481.1A, U.S. Department of Energy, June 1989.

DOE (1989b), "Radiation Protection for Occupational Workers", DOE Order 5480.11, U.S. Department of Energy, July 1989.

DOE (1989c), "General Design Criteria", DOE Order 6430.1A, U.S. Department of Energy, April, 1989.

DOE (1990), "Radiation Protection of the Public and the Environment", DOE Order 5400.5, February 1990.

EPA (1991), "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents", EPA 400-R-92-001, Environmental Protection Agency, October 1991.

LLNL (1996), "National Ignition Facility Preliminary Safety Analysis Report", UCRL-ID-123759, Lawrence Livermore National Laboratory, September 1996.

LLNL (1994), "National Ignition Facility Conceptual Design Report", UCRL PROP-117093, Lawrence Livermore National Laboratory, May 1994.

Consequence Category 4	100	10,000	100,000	1,000,000
Consequence Category 3	2.5	250	2500	25000
Consequence Category 2	5e-2	5	50	500
Consequence Category 1	1e-4	1e-2	0.1	1
	Frequency Category 4	**Frequency Category 3**	**Frequency Category 2**	**Frequency Category 1**

	Radiological Risk Level 1
	Radiological Risk Level 2
	Radiological Risk Level 3
	Radiological Risk Level 4

Figure 1: Risk Matrix for relative ranking of worker radiological release events

Consequence Category 4	2.5	250	2500	25,000
Consequence Category 3	0.1	10	100	1000
Consequence Category 2	1e-2	1	10	100
Consequence Category 1	1e-4	1e-2	0.1	1
	Frequency Category 4	**Frequency Category 3**	**Frequency Category 2**	**Frequency Category 1**

	Radiological Risk Level 1
	Radiological Risk Level 2
	Radiological Risk Level 3
	Radiological Risk Level 4

Figure 2: Risk Matrix for relative ranking of public radiological release events

Consequence Category 4	5e-2	5	50	500
Consequence Category 3	2.5e-3	0.25	2.5	25
Consequence Category 2	5e-4	5e-2	0.5	5
Consequence Category 1	1e-4	1e-2	0.1	1
	Frequency Category 4	**Frequency Category 3**	**Frequency Category 2**	**Frequency Category 1**

	Chemical Risk Level 1
	Chemical Risk Level 2
	Chemical Risk Level 3
	Chemical Risk Level 4

Figure 3: Risk Matrix for relative ranking of worker chemical release events

Consequence Category 4	2.5e-3	0.25	2.5	25
Consequence Category 3	5e-4	5e-2	0.5	5
Consequence Category 2	3e-4	3e-2	0.3	3
Consequence Category 1	1e-4	1e-2	0.1	1
	Frequency Category 4	**Frequency Category 3**	**Frequency Category 2**	**Frequency Category 1**

	Chemical Risk Level 1
	Chemical Risk Level 2
	Chemical Risk Level 3
	Chemical Risk Level 4

Figure 4: Risk Matrix for relative ranking of public chemical release events